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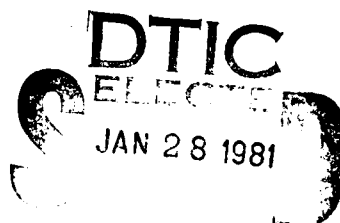
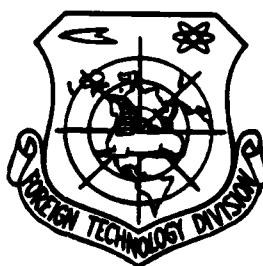
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RESEARCH ON STORM AND STRONG CONVECTION WEATHER

by

Tao Shi Yan, Ding Yi Hui, Zhou Xiao Ping



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## RESEARCH ON STORM AND STRONG CONVECTION WEATHER

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Our country is one of many storms; storms very frequently bring with them severe flood disasters. Since the beginning of socialist reconstruction, the flood disasters which occurred in the Yangtze River in 1954, the Yellow River in 1958, the Hai Ho in 1963 and the Huai River in 1975 were the products of fierce storms of a continuing character. Concerning the position in the geography of East Asia which China occupies, it is deeply influenced in the summer of every year by the summer winds. These vigorous seasonal winds or monsoons can reach North China, the Northwest and even into the area of Manchuria. With this sort of circulation background, and considering the complicated topography of China, all these effects frequently cause fierce storms in our country. This is obviously very different from the situation in the United States where strong convection weather is localized for the most part (tornadoes, thunderstorms, etc). After a particularly large rainstorm occurred in Henan Province in the first part of August 1975, the problem of rainstorms acquired the even more serious attention of the various meteorological agencies and departments. In 1977, China set up the south China pre-flood season rainstorm experimentation and observation net; moreover, China also developed a multifaceted cooperative effort for scientific research on rainstorms, carried through the work of these last few years, which obtained not a few important results and caused the levels research in our country in rainstorm forecasting to be

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quite significantly raised.

# 1 The Large Scale Circulation Background of the Occurrence of Rainstorms

Quite a few large rainstorms take place in periods when the large scale circulation gives birth to obvious readjustments; for example, the "August '75" rainstorm occurred during the period when the latitudinal direction of circulation in the area of East Asia was changing to a longitudinal direction. [1] The "July '58" super-rainstorm in the Yellow River was also given birth to during a period when the latitudinal long wave system in the Eastern Hemisphere was experiencing adjustments of positional opposition [2]. And again, in the period before the occurrence of the rainstorm of "July '58" (11-15 July), there were separate, stable long wave troughs at  $40^{\circ}\text{E}$  and  $110^{\circ}\text{E}$ ; between them, there was a long wave ridge between  $80^{\circ}$  and  $90^{\circ}\text{E}$ . After the 15th, the long wave system gave birth to speedy readjustments of positional opposition;  $80^{\circ}$ - $90^{\circ}\text{E}$  changed to become a stable long wave trough area, and  $40^{\circ}\text{E}$  and  $110^{\circ}\text{E}$  then changed to become long wave ridges. These types of readjustments caused long wave troughs as well as the high altitude cold vortex system to stabilize in the area of the western part of China; this, moreover, caused the Yellow River valley to give rise to continuous and violent rainstorms. Concerning the large scale circulatory form of rainstorms, we have done quite a bit of research in the past. For example, relying on the many particularly large rainstorms of our country and an analysis of these rainstorms, we generalized eleven types of circulatory forms for rainstorms [3]; among the, circulatory forms capable of producing large rainstorms or continuous rainstorms were particularly important. Given a longitudinal direction of circulation the basic characteristics of circulatory forms of large rainstorms and continuous

rainstorms were as follows: opposite peaks of stable high pressure over the Sea of Japan and the Qing Hai-Tibet area; cold upper air flows, without a break, along the front area of the high pressure over Lake Baikal and into the high altitude trough or shear line between the two areas of high pressure. Given a latitudinal direction of circulation, the basis characteristics of circulation forms of large rainstorms and continuous rainstorms were as follows: from the wide Siberian low trough, cold upper air which splits off southeast flows along continuously absorbing heat from the warm, moist air from the west side of the temperate high pressure zone; this creates continuous and violent rainstorms. In research on the large-scale circulatory forms of rainstorms, researchers in recent years have combined questions from three areas with illuminating results. First, the inter-related functioning of middle and low latitudinal circulatory systems, particularly the functioning of latitudinal systems of the low type. For example, during the periods of the rainstorms of "August '75" and "August '63" the tropical convergence area exhibited a clear northern thrust. During other periods of summer rainstorms, there were similar phenomena. The northern thrust of tropical convergence areas strengthened southwestern air currents and southeastern air currents and offered a large-scale source of water vapor; at the same time, various low pressure systems of the tropical convergence areas were able to directly contact the north, producing rainstorms. The most recent analysis also points out that [4] the tropical convergence areas always have a constant vortex in them when a typhoon touches land, if the sea surface still has low pressure over it or develops groups of structured vortices. At this time, there is formed a strong easterly air flow in the area between the group of vortices and the northern subtropical high pressure. This east wind extends from the sea directly into the interior of the land mass and becomes the principal conduit of water vapor

for rainstorms. Second, research on the large-scale circulatory forms of rainstorms has also combined in an illuminating way the blocking functions of subtropical high pressure and high pressure over the Sea of Japan. [5] The stable, sustained frequency of high pressure over the Sea of Japan is one of the principal reasons for the formation of rainstorms in general, or particularly large rainstorms in the northern area. These systems, in stable maintenance or in the westward stretch of areas of down drift, can cause rainstorm systems to change speed and slow down, stop or revolve; therefore, this condition is particularly advantageous for the formation of continuous, heavy rainstorms. Third, research on the large-scale circulatory forms of rainstorms has also combined in an illuminating way the function of weak, cold upper air. In not a few large rainstorms, it has been discovered that cold upper air, in lower layers, influences rainstorm areas from northwest and northeasterly directions; because of this, in the vicinity of rainstorm areas, it is often possible to analyze superficial restrained fronts.

## 2. Weather Systems Producing Rainstorms and Their Vertical Circulation

The weather systems producing the rainstorms of our country are very numerous; there are typhoons, cold fronts, low vortices, upper air troughs, shear lines, wet tongue areas on the northern side of subtropical high pressure, etc.; among these, typhoons have the greatest influence on rainstorms. Several pieces of research clearly bring out that, when typhoons combine with intermediate level latitudinal weather systems, the rainstorms produced are the strongest and most violent. For example, from the 17th to the 19th of October, 1967, there occurred, in Xin Liao on the Taiwan province of China, a typhoon rainstorm which, in a 24 hour period, reached a rainfall level of 1672mm, with a total

amount of rainfall for the three-day period of 2769mm. This storm was caused by nothing but the mutual interaction of a cold front with a typhoon. [6] It was the greatest single rainstorm ever recorded in China. Besides the systems discussed above, in research on the pre-flood season rainstorms of south China, it was also discovered that strong rainstorms could also be caused by several low-level, secondary-dimension weather systems (850 millibars and below). (The primary manifestation of this is low-layer shear lines). [7,8].

The three-dimensional air flow structure within rainstorm systems is extremely important to an understanding of the formation of rainstorms. Men like Browning have carried out considerable research. According to research done in recent years on the three-dimensional air flow structure of the various rainstorm systems of China, it is possible to generalize five types of circulatory flow structures.

The first type is the typhoon rainstorm circulatory structure (Fig 1a). The most advantageous area for the occurrence of rainstorms is on the east side or the northeast side of the typhoon circulation, where the strong ascending area created by the rapid flow of lower air to the east (or the rapid flow of lower air to the south) is located. The rapid flow of lower air also transports large amounts of water vapor. Moreover, the continuous addition of lower-level air flow toward the east and intermediate-level air flow toward the south (or toward the west) creates conditions for release of unstable form and for rebuilding. The vertical shear lines of the winds are very obvious. Often in this area low-level flow of cold air toward the north and air flow toward the east (or south) create medium dimension shear lines; this is a means of setting off strong convections. In the high layers, it is obvious anticyclonic

divergent circulation. All these conditions are advantageous for the development of cumulus rain clouds and rainstorms could be produced. [9] If upper-level divergent circulation is not present or has changed to convergent circulation, then formation of rainstorms will often be retarded; such conditions can only give rise to strong rainstorms of short duration. The typhoon rainstorms in the Beijing area on 25 July 1978 and 27 July 1972 were both this type.

The second type of circulatory structure has basic characteristics as follows: the lower levels are low vortex systems; the high levels (200 millibars and above) exhibit clear anticyclonic circulation; on both the north and south sides there is often an air flow toward the east and south, which strengthens the divergent flow of these layers (Fig 1b). This type of structure, which exhibits lower air convergence and upper air divergence, is advantageous for the continuing appearance of strong convection in rainstorm areas. It often appears in the pre-flood season rainstorms of south China. The great Hong Kong rainstorms of 12 June 1966 and the middle of June 1972 [10] as well as the great rainstorm in Taishan in Guang Dong Province on 28 May 1973 (in both these areas the amounts of rainfall reached a total of 850mm in a 24-hour period) were all this type of situation.

The third type is a ring of vertical circulation related to northern low trough cold front rainstorms [11] (Fig. 1c). On a vertical cross-section of the cold front, encircling the area of the storm, there are two clear rings of circulation. Fierce rainstorms appear in the rising branch of the vertical circulation ring on the east side or the south side. If a rapid movement of lower air is present, the flow of rising air is located in front of or to the left of the axis of the jet stream. Another clear characteristic is that on the

northern or western sides there is usually cold air sunk down from the middle and upper strata; this flows directly in front of the front, and it flows together with air from the south or the east, strengthening, yet again, the air flow in the rising branch. Therefore, this type of cold front rainstorm or strong convection activity appears primarily in the strong rising air currents of the forward section of the front. The fast-moving cold fronts of the south China summer often fit this type of model.

The basic characteristics of the vertical circulation structures of upper air cold front rainstorms are analogous to Fig 1c; however, strong and violent vertical currents of rising air appear principally in the upper part of convection layers. The particularly heavy rainstorm which occurred in the border area between Inner Mongolia and northern Shaanxi Province on the afternoon of 1 August 1977 (the total amount of rainfall from this storm reached 1050mm in 8 hours) was just this kind of situation. [12].

The fourth type is a vertical circulation structure which represents the rainstorms of the rainy season in the Yangtze, Huai and Mei river valleys as well as the quasi-stationary front rainstorms of south China (Fig 1d). Due to cold air volatility or weakness, the height of the front is low, its angle of slope is small, and warm air is active. The principal significance of this is that warm, moist air from the south initiates an upward slide along the face of the front. Rainstorms occur in the unstable air currents of these slanted rising formations (the surface cold front is between 700 millibar shear lines). If the cold air is relatively strong, the slanted rising air currents along the surface of the front are capable of turning over and rising vertically on the front [13, 14]. The vertical circulation

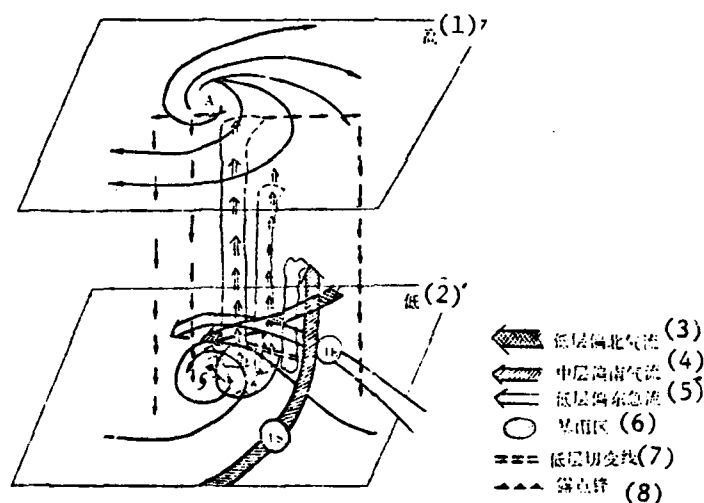
of the rainstorms of the south China quasi-stationary front and the structure of rains in the valleys of the Yangtze, Huai and Mei rivers are very similar; for the most part they both have unstable air flow along the strong formations of the slanted rise of the middle and lower strata.

The fifth type is vertical circulation related to warm shear lines [15, 16]. Due to the fact that the convergence of wind direction in the vicinity of the shear lines is strongest and most violent, there exists a strong and violent upward air flow. Most shear lines are nearly vertical; rainstorms and strong convection appear in the vicinity of the shear lines (Fig 1e). If there exists a low level jet stream in the southward flow of warm, moist air on the south side of the shear lines, due to the fact that the convergence of wind speed in its center is far from comparable to the convergence of wind direction in the vicinity of the shear lines, rainstorms and strong convection can appear south of the surface shear lines.

### 3. Physical Conditions for the Occurrence of Rainstorms and Strong Convection

There is an intimate relationship between rainstorm and strong convection weather and its circulatory conditions (including heating power and motive power). Large scale circulatory conditions not only restrain the nature of rainstorm and strong convection weather as well as its development process, it can also influence the structures within convection systems, their strength, motion and degree of organization. In large scale circulations, organized convection systems are not created and distributed according to chance; on the contrary, they occur within specific areas and periods of time. The physical conditions for the occurrence

of rainstorm and strong convection weather had already been inferred by induction in the past; in general, the following conditions have to be satisfied: (1) There must be unstable forms of stratification. It is also necessary to have in existence an opposing warm layer to thunderstorm systems. (2) Lower strata must have a convergence of moist tongues or water vapor. (3) There must be a mechanism for the release of unstable forms (for example, lower air conversion, gravity waves, density flow, terrain, etc.). (4) There must often be a low air jet stream and a high air jet stream in existence. (5) Strong thunderstorms require the presence



(9) 图 1a 持续性台风暴雨的环流结构

Fig 1a

Key: 1. Upper Layer 2. Lower Layer 3. Northerly air flow in the lower layer 4. Southerly air flow in the middle layer 5. Easterly Jet Stream in the Lower Layer 6. 7. Lower Layer Shear Line 8. Dew Point Front 9. Fig 1a Circulation Structure of Continuous Typhoon Rainstorm

of strong vertical wind shear. (6) Middle level air in strong convection weather will be cold and dry. At present, although there is a much greater understanding of rainstorm

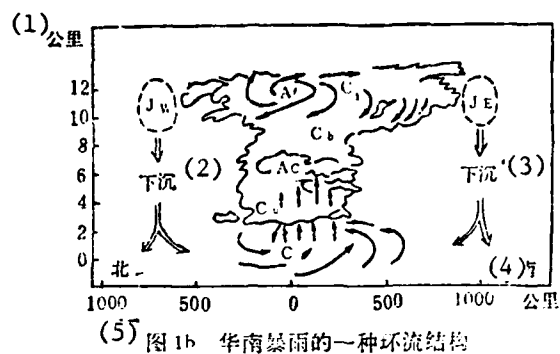


Fig 1b

Key: 1. Kilometers 2. Sinking Down 3. North 4. South  
5. Fig 1b A Type of Circulatory Structure of South China Rainstorms

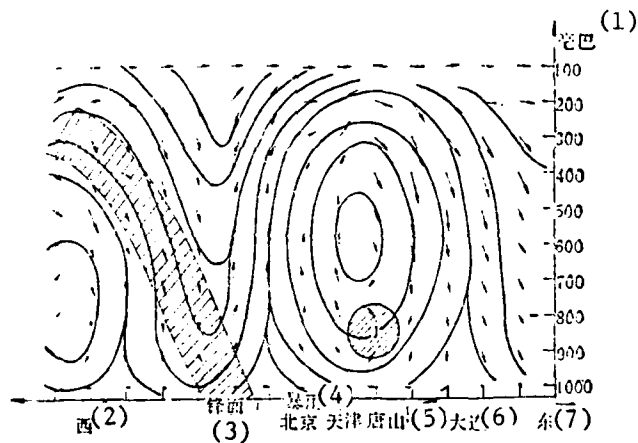
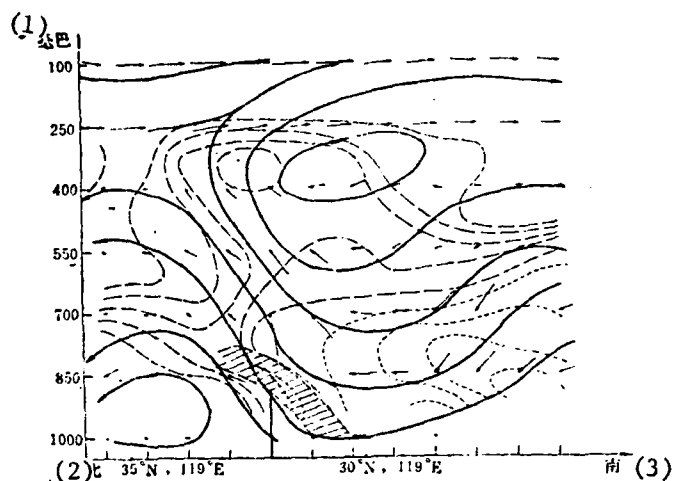


Fig 1c

Key: 1. Millibars 2. West 3. Front 4. Rainstorm 5. Beijing Tyan Jin Tang Shan 6. Da Lien 7. East 8. Fig 1c  
Circulatory Structure of Cold Front Rainstorm

and strong convection weather, it is still not completely clear what relationship there is in terms of physics, between these conditions and the development of medium scale systems; the causal relationship between the two has not been made



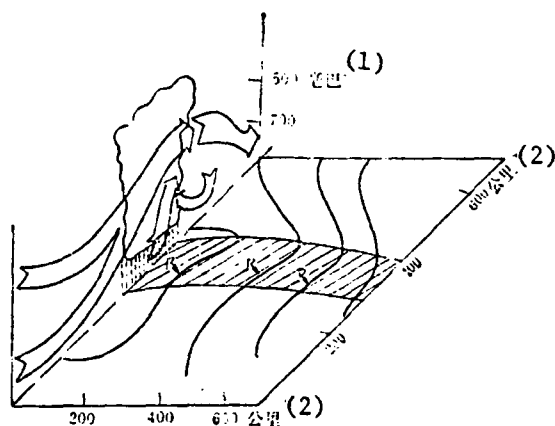
(4) 图 1d 准静止锋的环流结构

Fig 1d

Key: 1. Millibars 2. North 3. South 4. Fig 1d  
Circulatory Structure of Quasi-stationary Front

completely clear. This, to a very large degree, is due to the limitations of the observed information. It should be pointed out that rainstorm and strong convection systems are different from large scale circulatory conditions in the different phases of their development and in the degree of their mutual interdependence and interaction. During periods of occurrence and initial development, it is important to decide on the function of large scale environmental conditions; however, it is after rainstorm and strong convection systems attain strong and violent development that, even though large scale environmental conditions have lost their restraining function, these systems can still be influenced by convection storms.

In recent years, in research on various kinds of physical conditions, people have concentrated on the three problems below. The first is the function of lower air jet streams; a good number of statistics demonstrates that, no matter whether



(3) 图 1c 暖切变线的环流结构

Fig 1c

Key: 1. Millibars 2. Kilometers 3. Fig 1c The Circulatory Structure of Warm Shear Lines

it is in the north or the south [17,18], there is an intimate relationship between rainstorms and lower air jet streams; the mutual correlation rate reaches approximately 80%. In general, rainstorms occur most frequently to the left front of the axis of the jet stream or to the front of the center of the greatest wind speed. From the establishment of the lower air jet stream to the occurrence of rainstorms is, on the average, 2.5 days [19]. Because of this, the analysis of lower air jet streams most certainly has significance for forecasting purposes. The altitude of the axes of these jet streams is generally at the 1.5-3 kilometer level; sometimes in the border layer (950-900 millibars) it is still possible to discover yet another jet stream center. A good deal of analysis points out that the propagation interference movement along the axis of the jet streams is more important to rainstorms than are the main bodies of the jet streams themselves. People have discovered three salient facts: (1) High wind speed centers in lower air jet streams follow the axes of the

jet streams and propagate downward; corresponding rainstorm areas located to the front or left sides also move downward. Sometimes, in the process of a heavy rainstorm, it is possible to discover that there are several medium-dimension wind speed center propagations. Each large wind speed center has a companion vertical circulation ring existing with it; the front area of the large wind center is rising, and the rear area sinking. The rainstorm then appears in the strong rising air flow to the front of the wind speed center of the jet stream. Analysis also reveals that, following the propagation of the high speed wind center, the corresponding amount of heat, water vapor and the center of greatest value of the unstable air of the formation also propagate downward; because of this, lower air jet streams pass through the propagation movement, and the amount of heat and the water vapor of the downward movement of medium dimension pulse forms.

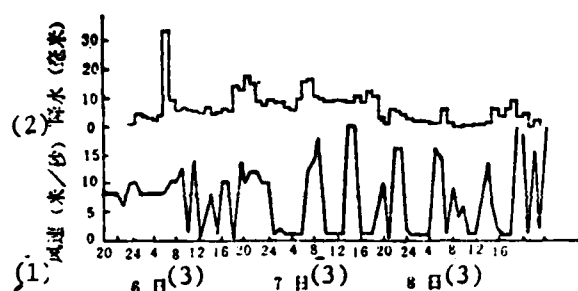
(2) According to research done in several cases on information on wind speed at high mountain stations, in one instance, in the process of propagation of medium dimension high-speed wind centers, changes in wind speed are very uneven, existing as a type of pulsation with an even shorter period but with a very large amplitude (these amplitudes may reach 10-12 m/sec) [20]. When a large jetstream wind speed center is passing through, this type of wind speed pulsation can appear 5-6 times; moreover, there is an extremely close relationship to changes and pulsations in the strength of rainstorms. Fig 2 indicates the relationship between rain fronts and changes in wind speed on Jiu Xian Mountain. Almost every time there was a rain front it corresponded to a strong and violent pulsation in wind speed. This may indicate that there is an intimate relationship between pulsations in wind speed and the formation of rain structures. (3) Lower air jet streams, in the entire process, most certainly do not exceed the ground loop; sometimes they are in ground loop equilibrium. It is only in areas of high wind speed or during periods of obvious

strengthening of wind speed that there occurs the phenomenon of exceeding the group loop. During the establishment and disintegration of group loop equilibrium, with changes in the wind field before and changes of air pressure field afterwards, rainstorms occur in periods of strong non-ground loop. The short period pulsations in wind speed, which were mentioned earlier, may have reflected a function or consequence of a series of gravity waves, which occurred due to non-ground loop motion.

Concerning the causes of the formation of lower air jet streams, there is still, at present, no uniform opinion. In the past, the habitual vibration of border layers was used to explain the formation of lower air jet streams during the night; later, there were those who emphasized the role of mountain ranges as barriers to lower air jet streams, thereby adding to their speed. In recent years, the downward circulation of the horizontal momentum has been used to explain the formation of lower air, medium dimension jet streams, thereby adding to their speed. In recent years, the downward circulation of the horizontal momentum has been used to explain the formation of lower air, medium dimension jet streams. There are also those who use the non-ground loop winds produced when air pressure systems develop (for example, the strengthening of the west side of a low pressure area) to explain the formation of large scale, lower air jet streams. This problem is worthy of further research.

The second is the function of boundary layers. In research on rainstorms in north and south China, it was discovered that, during periods of rainstorm, horizontal convergence reached its highest value (approximately 950 millibars) at 500m [21,22]; moreover, water vapor and temperature values were also high, and the comparison of cold and warm air was most dramatic (Fig. 3). During periods when

rainstorms were weakening, the largest convergence values for boundary layers disappeared. Because of this, the contribution of the convergence of momentum, water vapor and heat in boundary layers to rainstorms is the greatest of all. Moreover, before rainstorms and heavy weather appear, the accumulation of momentum, water vapor and heat appears first in the boundary layers; the largest wind speed values in the boundary layers also appear first. Later these are transported upward. The results above make clear that boundary layers have an important function in the establishment of strata of unstable form, the supply of water vapor and the touching off of the occurrence of rainstorms.

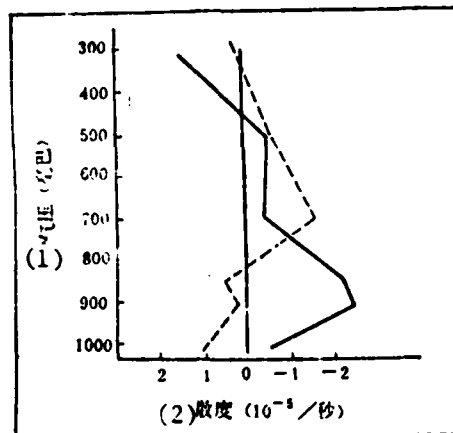


(4)图2 福建九仙山(海拔1644米)1978年6月6日—8日的风速变化(折线)和相应时间下游150公里内的最大降水量分布(方框线)

Fig 2

Key: 1. Wind Speed (m/sec) 2. Precipitation (mm) 3. Day  
4. Fig. 2 Wind Speed Changes (the wavy line) From 6-8 June 1978 at Jiu Xian Mountain in Fu Jian Province (Elevation 1644 m) and the Distribution of Amount of Precipitation Within 150 Km for Corresponding Time Periods (the squared-off line).

The third is research into the different physical conditions for rainstorm and strong convection weather (for example, hailstorms, thunderstorms and tornadoes). According to a comparison between the average stratification of rainstorms and strong convection weather, during periods when strong convection weather is present, in strata near the sur-



(3) 图3 暴雨加强(实线)和减弱时(虚线)  
北京散度垂直廓线(单位:  $10^{-5}$  秒 $^{-1}$ )

Fig 3

Key: 1. Air Pressure (Millibars) 2. Level of Diffusion ( $10^{-5}/\text{sec}$ ) 3. Fig 3 A Vertical Silhouette of the Level of Diffusion at Beijing During Periods of Strengthening and Weakening of Rainstorms (The solid line is strengthening; the broken line is weakening), (Units:  $10^{-5} \text{ sec}^{-1}$ ).

face, there is an inverse warm layer or other equivalent layer in existence. In this condition there is no rainstorm. From 750 millibars upward, the temperatures in strong convection weather, when compared to those in rainstorms, must obviously be on the low side. At 400 millibars the two differ by  $8^{\circ}\text{C}$ . Because of this, at altitudes lower than 7 kilometers, the rate of decrease in strong convection weather is larger than that of rainstorms by  $1-3^{\circ}\text{C}/\text{kilometer}$ . This is the result of the activity of middle and upper strata of cold air. The layers in strong convection which have a latent capability for instability are also somewhat thicker than in the case of rainstorms; however, free convection altitudes must be somewhat higher (Table 1). This explains the fact that strong convection weather requires stronger causative conditions. However, despite this fact, once the strong convection weather has been precipitated, the strength

level of the development of the convection will be much stronger than for rainstorms. The differences between the physical quantities of the boundary are also very great. The humidity present when rainstorms occur is, of course, much greater than that which is needed when strong convection weather occurs. It is also very obvious that the highest possibility of precipitation, the overall convergence of water vapor in strata, the vertical transportation of water vapor, etc., all respond to differences in the quantities of water vapor causation and water vapor capacity. The overall convergence of water vapor can be three times larger in rainstorms than in strong convection weather. This demonstrates that, in order for rainstorms to continue, water vapor must show speeds of convergence toward the rainstorm area twice as great as those found in strong convection weather; moreover, in the case of strong convection activity, the relationship to the amount of water vapor contained in the main body of the air column at its inception is very strong.

Differences in vertical wind shears are also very obvious. Rainstorms develop in weak shear environments; strong convection weather develops in strong shear environments. Figure 4 is a comparison between average vertical shears in rainstorms in front of troughs and those found under strong convection forms; the differences between the two are very obvious. The principal cause of large differences in vertical shear lies in differences in upper air wind speeds. Strong convection systems are numerous in the vicinity of the axes of upper air jet streams, and rainstorms are numerous in an area 200-500 km south of the axes of the jet streams. Strong vertical shear is an important condition necessary for the continuation of strong convection storms.

Several differences in the physical quantities which display the nature of air masses are noteworthy. After comparing  $T_{d850}$ ,  $T_{d500}$ ,  $T_{850}$ ,  $T_{500}$ ,  $\theta_{sc850}$ ,  $\theta_{sc500}$ , one can arrive at the conclusions that: differences in lower air humidities are centrally important; the lower air in rainstorms is air high in temperature and moisture, and the moisture level of air in strong convection will be much smaller; it is also possible to take it to be a modified polar continental air mass. The differences between the temperature and humidity of upper strata are also very obvious; the air in middle layers of strong convections is exceptionally cold and dry; most particularly, the humidity is extremely low. The two can differ by  $13^{\circ}\text{C}$ . This is due to the fact that during the formation of strong convections the upper layers have obvious cold stratospherics. During rainstorms, below 500 millibars, the air is all relatively damp; the characteristic differences in temperature and moisture over altitude are very great. Because of this, after going through the analysis above, one can arrive at the conclusion that rainstorms occur primarily in air masses which are generously supplied with heat and moisture; the characteristics of rainstorms also primarily determine the nature of warmth and moisture in the middle and lower layers of air masses as well as the horizontal distribution of cold air within them; moreover, strong convection weather primarily determines the strength of cold air in the middle and upper strata (or cold continuous currents) as well as the vertical distribution of warm moist air in the middle and lower layers.

#### 4. Research on Medium Scale Systems

Rainstorm and strong convection weather are medium scale systems. Medium scale analysis and experimental research were carried out between 1963 and 1965 in the area of the lower reaches of the Yangtze River; not a few profitable results

were obtained concerning the conditions of occurrence of medium dimension systems, their rules of activity and their relationship to weather [24]. Beginning in 1976, there was also carried out some observation and experimental research on small and medium scale systems in the area of south China and the Xiang River Valley, and this research deepened even more our knowledge of the characteristics and basic facts concerning the medium and small systems that influence the weather of China [25]. There were problems from four areas in the research on medium dimension systems: (1) The activity characteristics and structure of medium scale systems; (2) The mechanisms involved in the birth, development and continuance of medium dimension systems, for example, what is the mechanism which touches off the occurrence of medium scale systems? Under what conditions can isolated cumulus clouds become organized into medium dimension systems? Under what conditions can isolated cumulus clouds become organized into medium dimension systems? Through what physical processes do the development and maintenance of medium low pressure and medium high pressure go? (3) The functioning of feedback of middle dimension systems on the environmental field of large scale systems; (4) The role of the amalgamation of middle dimension systems in the strengthening of middle systems and the development of strong weather. Among these (2) is taken to be the most important.

There is currently no unified opinion on the mechanism of initiation and organization of medium scale systems. One group believes that lower layer, medium scale or secondary weather dimension convergence lines and gravity waves are important mechanisms in the initiation of these systems. Other factors and systems such as cold fronts, topography, lower air jet streams, lines of wind speed discontinuity, dew point fronts, and sea winds, density flow, etc., are all also capable of initiating the occurrence of rainstorms

(1) 表 1 暴雨和强对流发生的物理条件比较

(2) 天气	(3) 物理量	(4) 凝结高度 (mb)	(5) 自由对流高度 (mb)	(6) 抬升指数 (°C)	(7) 对流层顶高度 (mb)	(8) 1-9公里平均递减率 (°C/100米)	(9) 10-12公里平均递减率	(10) 0°C层高度 (mb)	(11) K 指数	(12) 900mb 以下最高温度	(13) 900mb 以下最大比湿	(14) 975-275 mb 最大可能降水 (mm)
(15) 暴雨		935	820	3.5	119	0.63	0.67	600	35.1	27.3	17.5	4.8
(16) 强天气		835	670	5.2	227	0.72	0.40	630	34.8	21.5	13.5	3.1

(2) 天气	(3) 物理量	(17) 地面-500mb 水汽水平辐合*	(18) 边界层顶的水汽输送*	(19) 纬向风垂直切变 (10 <sup>-3</sup> 秒 <sup>-1</sup> )	$\theta_{re500}$	$\theta_{re850}$	$\Delta\theta_{re}$ (300-850)	$T_{d500}$	$T_{d850}$	$T_{500}$	$T_{850}$
(15) 暴雨		1.9	2.0	1.0	75.0	78.3	-2.9	-4.4	17.0	-2.2	19.4
(16) 强天气		0.85	0.55	3.5	56.4	63.4	-6.8	-17.3	12.1	-8.4	18.1

(20)\* 单位: 10<sup>-4</sup> 克/厘米<sup>2</sup>秒。

Key: 1. Table 1 A Comparison of the Physical Conditions of Occurrence of Rainstorms and Strong Convection Weather 2. Weather 3. Physical Quantity 4. Altitude of Condensation 5. Altitude of Free Convection 6. Indicator of Raise 7. Peak Altitude of Convection Layer 8. Average Rate of Decrease 1-9 km (°C/100m) 9. Average Rate of Decrease 10-12 km 10. Altitude of 0° Layer 11. K Exponent 12. Highest Temperature Under 900 mb 13. Highest Relative Humidity Under 900 mb 14. Largest Possible Precipitation 975-275 mb 15. Rainstorm 16. Strong (Convection) Weather 17. Horizontal Convergence of Water Vapor Surface-300 mb\* 18. Maximum Transportation of Water Vapor Through Boundary Layer\* 19. Latitudinal Wind Vertical Shear (10<sup>-3</sup> sec<sup>-1</sup>) 20. \*Unit: 10<sup>4</sup> gm/cm<sup>2</sup> sec.

and strong convection weather. The role of the various kinds of points of mutual encounter between lines of discontinuity in the initiation of storms is even greater. For example, among the discoveries during the analysis of rainstorms in south China, was the fact that along lines of mutual contact between two sea wind fronts pushed in toward the mainland interior it is possible to have very strong rain masses. Medium dimension cold air masses, expanding from middle and lower layers toward the forward areas of cold fronts, also have a role in the initiation of such systems. Besides this,

during periods when high air troughs coming from the west or shear lines are repeatedly present on the lines of convergence of boundary layers. The formation of medium rain-storm systems can also be triggered [26].

During the initiation and development of medium dimension systems, the most important thing is to explain the formation of medium scale low pressure, because it is generally conceded that most medium and high pressure is the result of feedback from precipitation. At present, there are three types of opinion on the formation of middle and low pressure: (1) Surface middle and low pressure is produced by the compensating downward air currents in the lower section of the stratosphere in front of medium dimension convection systems and the upper section of convection layers. (2) Middle and low pressure is produced by the downward movement of air which is caused by the evaporation cooling produced by the cumulus cloud cover which is developed. (3) Middle and low pressure is produced by a release process of condensation of latent heat. There are also people who believe that the mechanism of warm stratospherics is capable of causing upper air multiplication of heat as well as a drop in surface air pressure, thereby causing middle and low pressure [27]. It is impossible at present to state precisely which of these causative theories best fits the reality. The resolution of this question requires, on the one hand, more observed data and, on the other, more quantitative calculations and a greater use of mathematical models. As soon as middle and low pressure is formed, lower air convergence and water vapor supply is increased; the development of cumulus clouds is intensified, and, because of this, middle and high pressure can quickly strengthen itself, forming an air pressure pair or dichotomy. Going through this mutual functioning of medium and low pressure and medium and high pressure causes the convection belt or medium dimen-

sion rain belt to constantly spread forward; moreover, it constantly causes the forward area to develop new convection clouds. Medium dimension systems also constantly spread forward. The development and initiation of middle scale systems also extends to involve the problem of the mechanism of medium dimension instabilities. This question is related to the mutual functioning of several systems of different dimensions; there has been only insufficient research on the problem done on a theoretical level. In recent years, there have been researchers who have used the mechanism of "wave motion instability conditions of the No. 2 type" relating to gravity waves in order to explain the development and structure of medium dimension systems, and this research has excited the interest of people in the field.

Observation and analysis reveal that, when medium scale systems merge, there are frequently produced in these systems obvious developments or strengthenings; agitated and violent weather often occurs under these conditions [28]. At present, the causative mechanism which leads the merging of medium systems to bring about violent development of these systems is still not completely clear. There are those who maintain that, when medium scale systems merge, volume is enlarged, causing water vapor and heat to be transferred upward and increased; the development of convection is consequently even more agitated and violent. There are also those who believe that, under certain specific environmental conditions, when two thunderstorms, which are in different stages of development, approach each other, the rising air currents of the new thunderstorm and the sinking air currents of the old thunderstorm can cause the formation of an analogous, local convection system which produces strong wind storms; this, in turn, produces agitated and violent weather.

## 5. Kinetics Problems Related to Rainstorms and Strong Convection

In China, research on the kinetics and numerical forecasting of rainstorms has the three principal areas given below: (1) Kinetic analogues of large scale weather development before the occurrence of rainstorms and at the time of their occurrence; (2) Kinetic processes of several medium dimension systems which are related to rainstorms; and (3) The strong convection processes, etc., of cumulus rain clouds.

Building on the foundation of meteorological analysis, using the numerical analogues or mathematical models of kinetics, it is already possible to forecast the occurrence of precipitation which will give rise to levels greater than 100mm/day [29, 30]. The results of type comparisons of different grids demonstrate that, to be able to forecast rainstorm weather formations, a grid cannot be larger than 100km; otherwise, there is no way to describe the relatively small-scale circulation patterns which form rainstorms. In the last few years, there has been done some relatively profound research into the functioning of kinematic development as it relates to water vapor. The research into the area of the kinematics of moist baroclinic atmospheres, which was begun by Xie Yi Bing and others [31, 32], demonstrates that, under conditions in which water vapor is in sufficient supply and it is possible to obtain releases, the most unstable wave lengths of atmospheric long waves are capable of becoming greatly shortened. If the unstable wavelengths are:

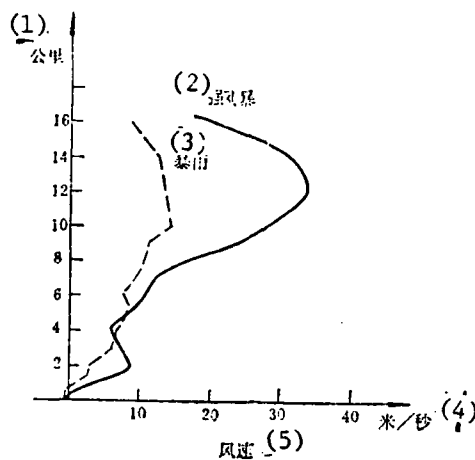
$$L_m = \left( - \frac{\alpha}{\theta_{se}} \frac{\partial \theta_{se}}{\partial p} \right)^{-1}$$

then, it is only necessary for the rate of decrease of moist

heat insulation to be approximately 0.7 in order for  $L_m$  to be approximately half the value of that variable under conditions of dry heat insulation. Although actual atmospheric conditions do not everywhere present such completely convenient or suitable conditions, nevertheless, this analysis done under extreme conditions explains clearly that it is not possible to overlook the role of water vapor; it is extremely important to rainstorms which form in a concentrated way in small areas.

Due to the fact that the scope of rainstorms in relatively small, even though the Glasshofer number, which is used to describe the functioning of increasing vertical speeds exhibited by movements at this type of scale, is smaller than 1, nevertheless, it is not so small that it becomes a number that can be ignored; because of this, the question of whether or not it is necessary to employ non-static force equations has become a disputed one. Research in recent years demonstrates that [33] it is necessary, in order to accurately describe the important functionings of gravity waves in the process of formation of rainstorm weather, to employ non-static force equations; this is due to the fact that, in specimens of static force, actual atmospheric gravity waves contain large distortions. A group of specimens of static force equilibria, which can be used in research on rainstorms and strong convection weather, is in the process of being designed. Having overcome a number of technical difficulties (such as initial values and boundary values) as well as having raised machine speeds and capacities, we can now hope for relatively large scale developments concerning the problem of mathematical forecasting of rainstorms. Concerning research in the area of the development of conditions of uneven stratification levels due to gravity and the subsequent formation of rainstorms and strong weather, there has also been a number of developments [34] which help

explain the ease with which the area to the left front of lower air jet streams can give birth to rainstorms.



(6) 图 4 暴雨(实线)和强对流(虚线)环境纬向风垂直切变的比较

Fig 4

Key: 1. Kilometer 2. Windstorms 3. Rainstorms 4. m/sec 5. Wind Speed 6. Fig 4 A Comparison Between the Vertical Shear of Latitudinal Winds in Rainstorms (Solid Line) and Strong Convection Environments (Broken Line)

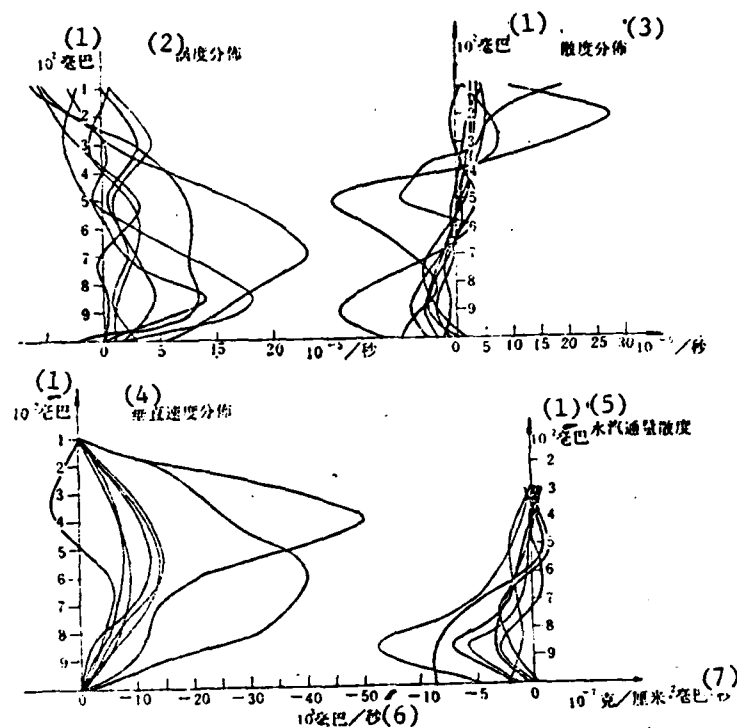
The development of rainstorms and the development of convection clouds cannot be separated. Kinetic research on the subject of cumulus clouds is an indispensable part of the kinetic study of rainstorms. In the early 60's, China had already begun research on the kinetics of cumulus clouds [35] and an analysis was done concerning the developmental situation of cumulus clouds under wind field conditions at different stratification levels. These analyses were the necessary foundation for kinetic analogues of pre-rainstorm conditions as well as for the mathematical forecasting of these conditions. However, in the last ten years, China has not greatly developed mathematical models of strong convection systems.

## 6. The Analysis and Forecasting of Rainstorms and Strong Convection

In recent years, in the analysis of rainstorms and strong convection weather, researchers have quite universally employed total energy analysis [36], and these same researchers have set forth quite a few telltale characteristics which can indicate the impending occurrence of windstorms. Relying on the energy analysis of vertical instabilities, researchers have generalized out various types of standard energy profiles which correspond to varying strengths of convection weather. Energy field analysis of horizontal instabilities indicates that rainstorms and strong convection weather frequently occur in the vicinity of  $\Omega$  type strong energy peaks. Several groups have also carried out kinematic diagnostic analysis of rainstorms. At present, some very helpful research and analysis is being done on rainstorms according to the objective kinematic diagnostic plan designed for research on rainstorms by the Geophysics Department of Bei Jing University and the Ji Lin Province Meteorological Authority. Fig 5 gives vertical distributions for the average vertical speeds ( $w$ ), diffusions ( $D$ ), vorticity ( $\xi$ ), and water vapor convergence ( $\frac{1}{g} \nabla \cdot vq$ ) for several examples of rainstorms as computed from corrected continuity equations. From these data it is possible to see that rainstorm areas occur in areas of lower air convergence and higher air divergence, in which the lower air is the primary area of vorticity, the upper air is the secondary area of vorticity and in which there are strong rising movements where thick strata are present. The maximum value of the rising movement is generally 500-600 millibars; the maximum values of convergence and divergence are respectively 900 millibars and 200-300 millibars. The maximum value of water vapor convergence also stands at 850 millibars; therefore, lower layer water vapor convergence is the principal source of water vapor for rainstorms. According to a diagnosis of the  $w$  equation,

it is possible to estimate the overall contribution of  $\omega$  as compared to other physical factors. Analysis of several individual examples of rainstorms demonstrates that the vertical movement produced by latent heat of condensation constitutes from 80% to 90% of the total value of  $\omega$ . This explains the fact that the role of feedback from latent heat of condensation is very large. However, as far as strong convection systems are concerned, the role of latent heat of condensation is small or it approaches zero.

Forecasting of rainstorms and strong convection weather is a difficult problem; it involves questions about the interrelated functioning of various weather systems of different dimensions. At present the level of development of the forecasting of rainstorms is not high either inside China or outside; moreover, what ability there is, is primarily limited to short periods (0-12 hours). Medium range forecasting of rainstorms, at present, depends primarily on circulatory background. In short range forecasting of rainstorms, there are three types of methods used. One is the synoptic empirical forecasting method; this method is further subdivided into two types: one is the weather form method, in which the distributional characteristics of various types of weather systems both at the time of the occurrence of rainstorms and before their occurrence are used in order to precisely fix the location of rainstorm areas. This method is employed universally in the meteorological stations of our country; its drawback is that it does not give enough consideration to the physical conditions that produce rainstorms. Sometimes, even in cases where the weather conditions are identical, it is possible that rainstorms will not occur. Moreover, in making predictions, it is often difficult to precisely determine the analogues of the weather forms. Besides this, it is frequently difficult to get accurate reports on rainstorm systems which develop



(8)图5 暴雨区散度(D), 涡度( $\zeta$ ), 垂直速度( $\omega = \frac{dp}{dt}$ ), 水汽通量散度( $\frac{1}{g} \nabla \cdot vq$ )的平均垂直分布。单位:  $\omega$ :  $10^{-3}$  毫巴/秒;  $D, \zeta$ :  $10^{-5}$  毫米/秒  
 $\frac{1}{g} \nabla \cdot vq$ :  $10^{-7}$  克/厘米<sup>2</sup>·毫巴·秒

Fig 5

Key: 1. Millibars 2. Vorticity Distribution 3. Diffusion Distribution 4. Vertical Speed Distribution 5. Water Vapor Flux Diffusion 6. Millibars/sec 7. Grams/cm<sup>2</sup> · millibar · sec 8. Fig 5 Average Vertical Distributions of Rainstorm Area Diffusion (D), Vorticity ( $\zeta$ ), Vertical Speed ( $\omega = \frac{dp}{dt}$ ), Water Vapor Flux Diffusion ( $\frac{1}{g} \nabla \cdot vq$ ) Units are:  $\omega$ :  $10^{-3}$  mb/sec;  $D, \zeta$ :  $10^{-5}$  mm/sec;  $\frac{1}{g} \nabla \cdot vq$ :  $10^{-7}$  grams/cm<sup>2</sup> · millibar · sec

and weaken rapidly and suddenly change their speed of movement. The second type of method is the area of fall or drop area method. This method depends primarily on the various physical conditions which exist when rainstorms occur in order to determine the location of the rainstorm area. This method,

since it takes into consideration physical conditions related to rainstorms, can frequently obtain relatively better results. Particularly after the "758" rainstorm, many groups started using the area of fall or drop area method on a trial basis [37]. However, one primary drawback of this method was that, for the most part, the parameters or indicators used were set at the time when the forecasting or observations began. This fact, in the case of relatively fast moving systems, made the rainstorm areas of fall report out inaccurately; because of this, it has been found best to employ physical parameters which are set at the time of the actual forecast; this problem can be solved using mathematical forecast methods. There are also lower air jet streams to act as primary indicators with which to make rainstorm forecasts [38].

The second type of method is the statistical method. At present, the method used relatively more frequently is the form differentiation statistical method. The strong point of this method is that it considers the special characteristics of various types of weather forms and employs a process which involves a group of factors which reflect the formation of rainstorms. Obviously, this method will be much better than one employing a set of factors which reflect the formation processes of various types of rainstorms (sic). However, the drawback of this method is that, sometimes, there are too many forms to be differentiated; moreover, transition forms are often difficult to deal with. There is also a method of rainstorm forecasting which employs discriminatory analysis. According to forecasting experimentation conducted at Central Station, forecasts of centers of rain belts and amounts of rainfall have been relatively uniform with the reality; however, there are too many reports of rainstorms which do not materialize. This is particularly hard on the rate of accuracy of reports of rainstorms.

The third type of method is a mutual combination of the numerical forecasting method and motive force-statistical forecasting method. The numerical method of forecasting has already been explained; the important thing now is to put it into the research and experimentation stage. The motive force-statistical forecasting method (MOS method) is already quite universally used, outside of China, for forecasting stressing various types of primary factors; researchers abroad have obtained definite results using this method. However, at present, due to the fact that the specialized numerical forecasting in China cannot offer adequate physical factors, development in this direction has not yet taken place.

Besides this, the Guang Da Prefecture Meteorological Station has accumulated a set of methods for making medium and short range rainstorm forecasts, for example, people at this station use a "nine line graph" and correlate many kinds of indicators and popular proverbs (sic) in order to make forecasts. This is a very good path to take toward an increase in the accuracy rate of rainstorm forecasts.

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